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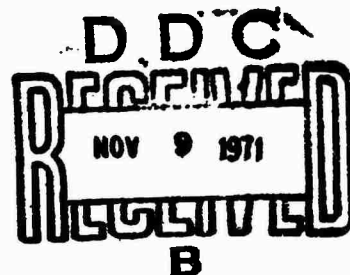
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Technical Memorandum 7-71

SMALL-ROCKET NOISE: HAZARDS TO HEARING

(Advanced LAW Program)

Georges R. Garinther
David C. Hodge



May 1971
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HUMAN ENGINEERING LABORATORIES



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ABSTRACT

Temporary threshold shifts₂ were determined for single exposures of subjects to impulses produced by the M20A1 and the M72 rocket launchers. These exposures were at levels up to 179 dB without hearing protection, and up to 184 dB with hearing protection. This study indicates that the CHABA impulse noise damage-risk criterion is valid for single impulses having durations of 12 to 34 milliseconds. The firer of the M72 is subjected to 179 dB which is greatly in excess of the exposure criterion; personnel should not be exposed to such conditions without hearing protection. The standard Army issue earplug (V51-R) nominally provides 25 dB attenuation for this type impulse and permits safe exposures up to 184 dB.

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SMALL-ROCKET NOISE: HAZARDS TO HEARING

(Advanced LAW Program)

INTRODUCTION

The development of a new, small shoulder-fired rocket launcher is being planned. This weapon will be similar in concept to the current M72A1 Light Antitank Weapon (LAW). The experiments described in this report were performed to evaluate impulse-noise hazards in existing small-rocket systems and to develop impulse-noise exposure limit recommendations for designers of the new system.

The following noise parameters must be determined to assess the potential hearing hazard of a single impulse from a shoulder-fired rocket:

- a. Peak pressure level, which is the highest pressure achieved (expressed in dB re $20 \mu\text{N/m}^2$).
- b. B-duration, the time that the envelope of pressure fluctuations (positive and negative) is within 20 dB (1/10) of the peak pressure.
- c. Ear orientation or incidence with respect to the noise source: normal incidence (0°) means the ear is facing the source, while grazing incidence means that the ear is at 90° from the source.

Rocket-noise exposures differ from other types of impulse-noise exposures in two important respects. First, the peak pressure level at the firer's position is generally much higher, and the B-duration is considerably longer than that produced by small arms. Second, a typical daily exposure in training (or combat) is one impulse, i.e., firing one round, whereas with smaller (and larger) caliber closed-breech weapons, several, or many rounds, may be fired per day. These differences dictated that an empirical examination of the hazards of small-rocket noise be performed. Current damage-risk criteria (DRC) may not be applicable to single, long-duration impulses, since they have been developed in the main from studies of exposure to many, short-duration small-arms noises.

The only generally accepted hearing DRC for impulse-noise exposure is that published in 1968 by CHABA ("CHABA" refers to the Committee on Hearing, Bioacoustics and Biomechanics of the National Academy of Sciences, Washington, D. C.) (1). This DRC limits temporary threshold shift two minutes after exposure (TTS_2) to:

- 10 dB at or below 1000 Hz
- 15 dB at 2000 Hz
- 20 dB at or above 3000 Hz.

Protection of 95 percent of exposed ears against TTS_2 exceeding those shown above is provided by the DRC. Thus, in this report, the above TTS_2 limits are referred to as "CHABA C₉₅."

A three-phase program was conducted to evaluate hearing hazards from noise of small rockets:

In Phase I, unprotected ears were exposed to single rocket noises to establish the hazards involved. In addition, the validity of the single-impulse correction factor of the CHABA (1968) impulse-noise DRC was tested.

Phase II was concerned primarily with establishing exposure limits for firers wearing hearing protection. Both grazing and normal-incidence exposure were used.

Phase III was conducted to replicate certain aspects of the first phase and to examine further the effects of unprotected-ear orientation on temporary hearing losses.

The results of these investigations clearly show the hazards associated with firing the current M72 LAW rocket, hazards which are considered to be excessive in light of current DRC. Further, well-fitted hearing protection, regularly used by firers, would permit the firing of weapons producing noise as intense as, or somewhat higher than, the LAW rocket without excessive risk of injury to firers. These conclusions are supplemented with recommendations for follow-on research.

METHOD

Test Conditions Common to All Phases

1. Range area. All rocket firings were conducted at the Duck Lane Range, Spesutie Island, at Aberdeen Proving Ground. This range area (Fig. 1) consisted of a large, relatively flat field, approximately 400 meters square. Terrain discontinuities were minimal, and the grass cover was mowed to a height of about six inches during the test period.

2. Subjects. Subjects (Ss) for these tests were Army enlisted men who were placed on temporary duty at the Human Engineering Laboratories (HEL) for this purpose. They were selected by medical personnel at their home stations to be free of chronic otolaryngological problems and to demonstrate hearing levels not exceeding +15 dB (re ANSI 1951 audiometric zero) at frequencies of 500-6000 Hz in both ears.

3. Audiometers. The Ss' hearing thresholds were measured at 500-6000 Hz with Rudmose ARJ-4 automatic audiometers. These instruments were modified as described by Hodge and McCommons (3), and had been further modified by the inclusion of an electronic switch to produce pulsing tones. The use of a pulsing tone has been found to provide the most reliable index of hearing sensitivity after noise exposure, particularly when the S is experiencing tinnitus.

4. Hearing Test Van. Hearing threshold measurements at the range were conducted in a modified shop van (Fig. 2). The van body was partitioned into two small rooms. The outer room was used for instrumentation, while the inner room served as a relatively quiet audiometric test chamber. Due to the low ambient sound levels in the range area, plus the attenuating properties of the van body and the Otocup^H enclosures used on the Ss' earphones, the sound pressure levels reaching Ss' ears were considerably below the minimum standards for audiometric testing.

5. Noise Measurements. Measurements were made using Susquehanna Instrument Model ST-2 pressure transducers. During the exposure, the transducers were always positioned at grazing incidence as recommended in HEL Technical Memorandum 11-65, "Transducer Techniques for Measuring the Effect of Small-Arms' Noise on Hearing" (2). The transducer system was connected to an oscilloscope and the waveshape was photographed. The parameters used to

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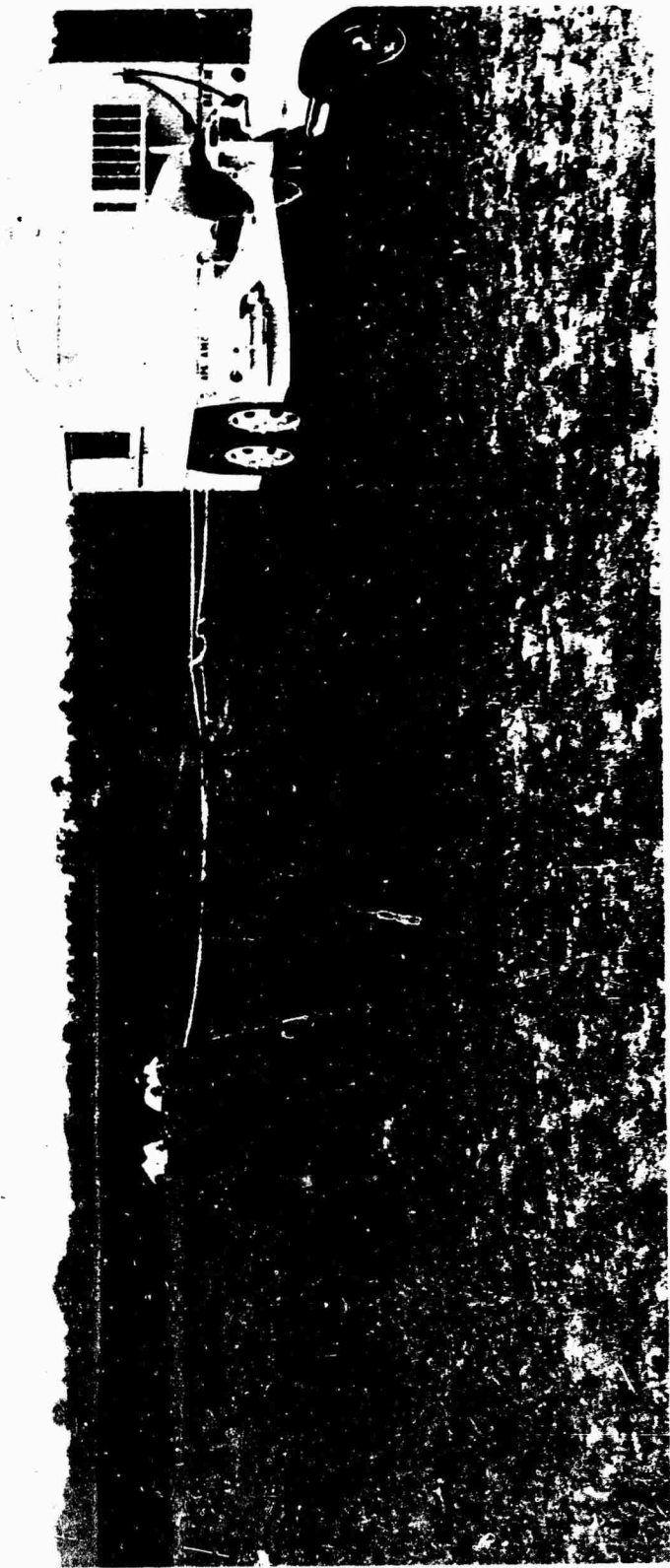


Fig. 1. DUCK LANE RANGE, SPESUTIE ISLAND
(Fixed rocket stand located in left center. White tapes define
blast hazard area behind rocket. Trailer houses noise-measuring instrumentation.)

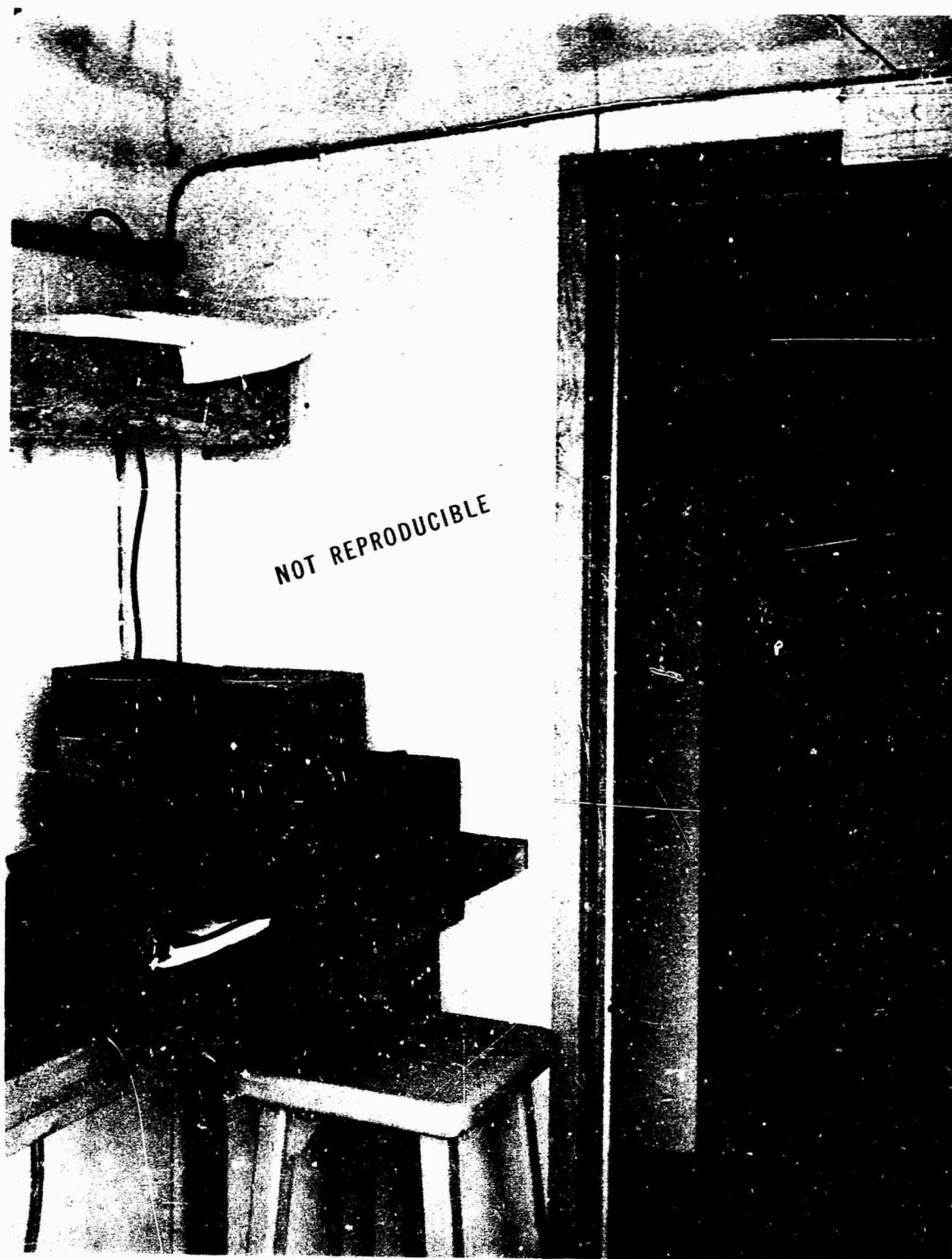


Fig. 2. INTERIOR OF SHOP VAN SHOWING AUDIOMETER ROOM (FOREGROUND)
SEPARATED FROM SUBJECTS' TEST ROOM (BACKGROUND) BY A
SOUND-ATTENUATING DOOR

evaluate the noise - peak pressure level and duration - were obtained from this oscilloscope photograph. Prior to the exposure of Ss, the desired peak pressure level and duration on both sides of the weapon were located by averaging at least three measurements at the center of the intended head locations.

6. Procedure. Upon their arrival at Aberdeen Proving Ground, the Ss were given a briefing to explain the purposes of the rocket-noise tests. A personal and medical history was taken, and the Ss were trained to give reliable hearing thresholds with the Rudmose audiometers.

Rocket-noise exposures were scheduled on the basis of half-day sessions. Eight to 16 Ss were transported to the range area for each morning or afternoon session. At the range, the Ss were tested and exposed to noise in pairs (one S on each side of the noise source) with the remaining Ss waiting in a covered position remote from the exposure location.

Two Ss were taken into the audiometric test van and given pre-exposure hearing tests. They then walked down to the exposure position where final instructions were given. The fixed-mounted rocket was fired remotely on the command of, "Ready, one, two", to insure that all recording instrumentation was started at the proper time. At the moment of firing, a stop watch was started to provide a time base for post-exposure hearing tests. After the rocket was fired the Ss returned to the audiometric van where a post-exposure hearing test was started at two minutes. At the conclusion of this test the pair of Ss returned to the waiting area and the procedure was repeated with another pair of Ss. At the conclusion of each session the group of Ss was returned to their billets.

Recovery testing was conducted to insure that Ss' hearing thresholds had returned to normal before they were scheduled for re-exposure. These tests were conducted about four and 24 hours after exposure. Ss were not re-exposed until their thresholds had returned to within at least 5 dB of pre-exposure baseline.

Pre- and post-exposure hearing thresholds were recorded on the same audiogram card, in black and red ink, respectively. Thresholds were scored by one of two procedures, depending upon the S's responses. (The same scoring procedure was used before and after exposure for a given S.)

- a. If the maximum excursion of the S's trace was 10 dB or less, the midpoints were averaged.
- b. If the excursions were greater than 10 dB, the tops of the traces were averaged.

The difference between the pre- and post-exposure tests was scored to the nearest dB, with positive sign indicating a temporary loss of sensitivity (i.e., temporary threshold shift - TTS) and a negative sign indicating an apparent gain in sensitivity. Positive $TTS \leq 35$ dB, measured in real time from two to eight minutes after exposure, were converted to a common time base of $TTS_{2 \text{ min}}$ using the method of Kryter (5). Positive $TTS > 35$ dB, and negative TTS, were not so converted since the method is clearly inappropriate for these types of data.

Specialized Test Conditions

1. Phase I

- a. Noise Sources. Two sources of rocket noise were employed in Phase I: M72 LAW rounds, and M29 rounds fired from an M20A1 (3.5 in.) rocket launcher. These sources

provided significantly different noise waveforms, the former having a B-duration on the order of 12 msec while the latter's B-duration was about 34 msec.

b. Exposure Distance. Ss were exposed at three distances from the M72 LAW and at one distance from the M20A1 rocket launcher. The first S exposure locations for both sources were calculated to give exposures equivalent to the permissible peak pressure level and B-duration limits of the 1968 CHABA impulse noise DRC for a single impulse with the ears at grazing incidence. The third exposure location for the M72 was at the firer's position, where the S assumed a kneeling position at the fixed-mounted launcher, placed his head at the firer's position, and actually triggered the rocket. At this location, the S's right ear was oriented about midway between normal and grazing incidence with respect to the noise source (rocket breech) while his left ear was shadowed by his head. The second M72 exposure location was at a point where the peak pressure level was intermediate to the first and third locations, and the S's ears were oriented at grazing incidence. The peak pressure level and B-duration used for these three exposures are summarized in Table 1, and detailed measurements are presented in Appendix A. Photographs showing actual Ss at the various exposure locations are included in Appendix B.

2. Phase II.

a. Noise Source. For this phase, rocket noise was produced by firing M72A1 LAW rounds. The M72A1 is acoustically equivalent to the M72 LAW at the exposure locations used in this phase.

b. Ear Orientation. Both grazing and normal ear incidence were used in Phase II. Grazing exposures were conducted first, followed by exposures at normal incidence.

c. Hearing Protection. All Ss in Phase II wore V51-R earplugs for all noise exposures, since the primary purpose of this phase was the determination of exposure limits for aurally protected personnel. The earplugs were individually fitted for each ear, and plug fit was rechecked by the test director immediately prior to each noise exposure.

d. Exposure Distance. Phase II exposures were conducted along an azimuth of 45° from the rear of the rocket. This azimuth was chosen because B-duration was found to be relatively invariant at distances up to 25 meters from the rocket, and because it permitted achievement of a maximum peak pressure level of 184 dB at the closest exposure location.

The first grazing-incidence exposure location was calculated to equal the CHABA DRC peak pressure level limit, plus 15 dB. The 15 dB addition was used as a conservative estimate of the amount of impulse-noise attenuation provided by V51-R earplugs. (As it turned out, this was a very conservative estimate.) The second and third grazing-incidence locations represented increases of 5 and 9 dB, respectively, in peak pressure level over the first location.

Since it was determined during the grazing-incidence exposure that the hazard to protected Ss was less than had been assumed, the first normal-incidence exposure location was the same as that used for the first grazing exposure. This means that we were assuming 20 dB attenuation for the earplugs since, according to the CHABA DRC, normal exposure is 5 dB more hazardous than grazing exposure. The second and third normal-incidence exposures thus also represented peak pressure level increases of 5 and 9 dB, respectively, over the first exposure.

TABLE 1

Peak Pressure Level and Duration of the Rocket Noises
at the Exposure Locations for Phase I^a

Distance (m) ^b	M72		M20A1	
	Peak Level (dB) ^c	Duration (msec)	Peak Level (dB)	Duration (msec)
8	160.8	12.3	-	-
4	-	-	159.3	34.1
2.5	169.5	14.1	-	-
Firer (rt ear) ^d	179.7	12.0	-	-

^aMeasurements were made at the position of the downrange ear with the subject absent.

^bPerpendicular to the tube at the sight.

^cdB re 20 $\mu\text{N/m}^2$.

^d13 cm behind; 3 cm below; 0 cm rt of the sight eyepiece.

A summary of the peak pressure levels and B-durations of Phase II exposure locations are shown in Table 2, and complete noise measurement data are listed in Appendix A. Photographs of S₅ at the various locations and orientations are shown in Appendix B.

3. Phase III.

a. Noise Source. The M72A1 LAW was used.

b. Ear Orientation. Three ear orientations were used: grazing impulses arriving from the rear (grazing rear), as for the first exposure of Phase I; grazing impulses arriving from the front (grazing front); and normal, where one ear was normal to the oncoming shock wave.

c. Exposure Distance. Phase III exposures were conducted at a distance of 21 meters on an azimuth of 45° from the rocket breech. At this point, the peak pressure level and B-duration (161.9 dB; 9.3 msec) were equivalent to that used in Phase I for the first M72 LAW exposure (according to the CHABA DRC, a doubling of duration is equivalent to a 2 dB increase in peak pressure level).

TABLE 2

Peak Pressure Level and Duration of the M72A1 Rocket
Noise at the Exposure Locations for Phase II^a

Position	Distance (m) ^b	Peak Level (dB) ^c	Duration (msec)
1	4.0	175.0	9.7
2	2.3	179.6	10.1
3	1.5	183.7	9.6

^aAverages of data obtained 33 cm to the right and left of the center of the head with subject in place.

^bOn an azimuth of 45° from the breech of the weapon.

^cdB re 20 μ N/m².

RESULTS

A total of 43 Ss (86 ears) were tested in Phase I, 42 Ss (84 ears) in Phase II, and 33 Ss (66 ears) in Phase III. Not all Ss in any phase participated in all test conditions, however. Some Ss demonstrated slow recovery, were granted emergency leave or contracted colds, and were, therefore, temporarily unavailable to serve under particular conditions. In the authors' opinion, a sufficient number of Ss were available for each test to permit meaningful conclusions and recommendations to be formulated.

Since the primary intent of the studies was to compare the overall response of groups of Ss with established noise-exposure criteria, it was not necessary to resort to extensive statistical treatment of the data in developing conclusions and recommendations. The data are reported as centiles (50th, 95th and 100th) of TTS_2 —abbreviated C_{50} , C_{95} and C_{100} .

Phase I

Table 3 summarizes the TTS_2 data from those exposures calculated to produce CHABA C_{95} TTS_2 from the M72 and M20A1 rocket launchers. The percentage of ears exceeding the CHABA C_{95} TTS_2 limits are shown in Table 4. Taken together, the data in Tables 3 and 4 indicate that for the M72 exposure, the resulting TTS_2 slightly exceeded CHABA C_{95} limits, while for the M20A1 exposure, the results were slightly more conservative than the DRC limits. This bracketing of results, predicted from the CHABA DRC, leads to the conclusion that the CHABA single-impulse correction factor is valid.

Table 5 presents a summary of the data for the intermediate M72 exposure. As expected, the increased peak pressure level of 8.7 dB resulted in a slight overall increase in TTS_2 .

Table 6 shows the results for the exposure at the operator's position of the M72. It is obvious that the uncorrected $TTS_{2.8}$ resulting from this exposure was excessive in comparison with the CHABA limits (the $TTS_{2.8}$ data were not converted to TTS_2 because the high incidence of $TTS > 35$ dB made such a conversion inappropriate). Only 28 Ss (56 ears) were tested under this condition since the test was terminated as soon as the excessive hazard was recognized. The obvious difference in TTS, demonstrated in the left and right ears (of a right-handed firer) at the operator's position, resulted from the head orientation: the right ear is pointed somewhat toward the breech (noise source) whereas the left ear is shadowed by the head. These points will be discussed later in more detail.

In Figure 3 the 95th percentile TTS's, produced by the M72, are plotted, along with the CHABA limits on C_{95} . The figure dramatically illustrates the hazard at the operator's position of the LAW, in that CHABA-limit TTS was exceeded at all frequencies in both ears, except for 1000 Hz in the left, shadowed, ear.

Phase II

Table 7 summarizes the TTS_2 resulting from the grazing-incidence exposures at the three positions when the Ss wore well-fitted earplugs. Only at the 500 Hz frequency for Exposure Position 2 did the observed C_{95} TTS_2 exceed the CHABA DRC limits: six percent of the 84 ears exceeded the CHABA C_{95} limit, or one percent more than permitted by the DRC. Overall, these data suggest that grazing-incidence exposures to single impulses do not produce excessive hazards at peak pressure levels of 184 dB (B-duration, 9.6 msec).

TABLE 3

Temporary Threshold Shift₂ at CHABA-Limit Position
of M72^a and M20A1^b
(Grazing Incidence)

Frequency (Hz)	CHABA C ₉₅	Temporary Threshold Shift ₂ (dB)					
		M72 (N = 86)			M20A1 (N = 55)		
		C ₅₀	C ₉₅	C ₁₀₀	C ₅₀	C ₉₅	C ₁₀₀
500	10	0	8	13	0	11 ^c	13
1000	10	0	6	13	0	11 ^c	11
2000	10	0	7	11	0	7	9
3000	20	0	11	16	0	11	14
4000	20	0	16	21	0	12	16
6000	20	0	21 ^c	37	0	19	27

^aPeak Level, 160.8 dB; B-Duration, 12.3 msec.

^bPeak Level, 159.3 dB; B-Duration, 34.1 msec.

^cDenotes instance in which observed TTS₂ exceeded CHABA limit.

TABLE 4

Percentage of Ears Exceeding Temporary Threshold Shift₂
Limits of CHABA Damage-Risk Criterion^a

Frequency (Hz)	M72	M20A1
500	2.2	3.6
1000	1.1	3.6
2000	0	0
3000	0	0
4000	0	0
6000	7	3.6

^aCHABA DRC permits 5% of exposed ears to exceed criterion hearing losses.

TABLE 5

Temporary Threshold Shift₂ at Intermediate Exposure Position
of M72
(Grazing Incidence; N = 86 Ears)^a

Frequency (Hz)	Temporary Threshold Shift ₂ (dB)				Percent of Ears Exceeding CHABA C ₉₅ ^b
	CHABA C ₉₅	C ₅₀	C ₉₅	C ₁₀₀	
500	10	0	14	26	6
1000	10	0	18	26	8
2000	15	0	13	19	1
3000	20	0	17	38	5
4000	20	0	16	21	1
6000	20	3	25	45	9

^aPeak Level, 169.5 dB; B-Duration, 14.1 msec.

^bCHABA DRC permits 5% of exposed ears to exceed C₉₅ TTS₂.

TABLE 6

Temporary Threshold Shift_{2.8} at Operator's Position of M72^a

Frequency (Hz)	TTS ₂ (dB) CHABA C ₉₅	Left Ear (N = 28)				Right Ear (N = 28)			
		TTS _{2.8} (dB)			% Ears Exceeding CHABA C ₉₅ ^b	TTS _{2.8} (dB)			% Ears Exceeding CHABA C ₉₅ ^b
		C ₅₀	C ₉₅	C ₁₀₀		C ₅₀	C ₉₅	C ₁₀₀	
500	10	0	13	26	7	3	20	21	18
1000	10	0	8	11	4	5	24	43	32
2000	15	0	25	37	14	7	40	48	18
3000	20	2	22	48	7	6	53	75	29
4000	20	4	36	48	7	10	69	76	29
6000	20	7	25	49	14	9	75	81	36

^aPeak Level, 179.7 dB; B-Duration, 12.0 msec.

^bCHABA DRC permits 5% of exposed ears to exceed C₉₅ TTS₂.

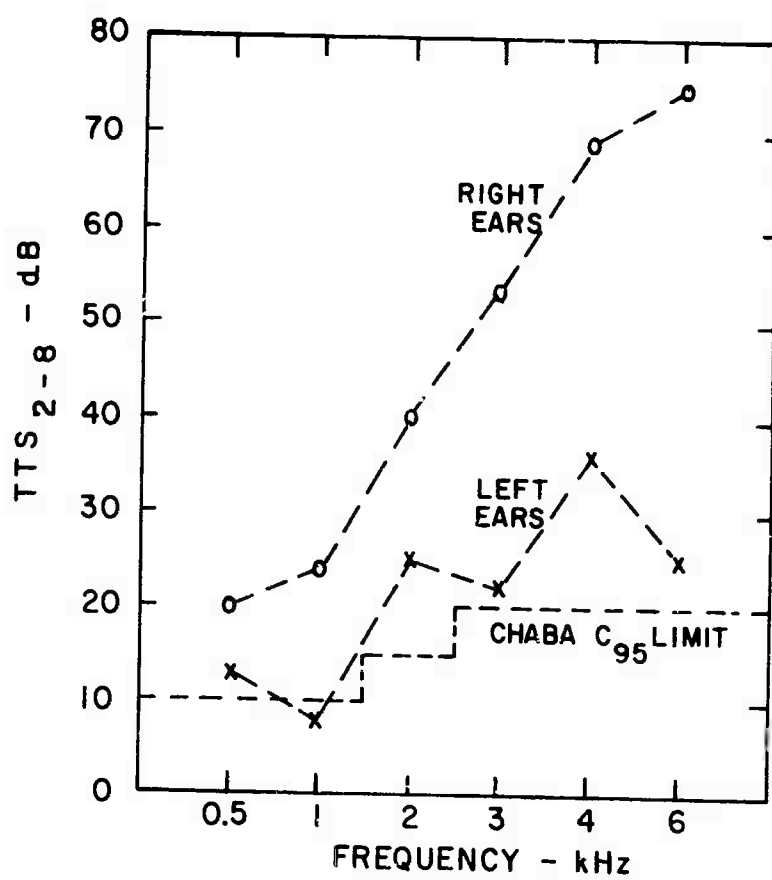


Fig. 3. C₉₅TTS AT OPERATOR'S POSITION OF M72 LAW COMPARED WITH CHABA C₉₅ LIMITS

TABLE 7

Temporary Threshold Shift₂ at Three Grazing-Incidence
Exposure Positions With Hearing Protection (Phase II)

Frequency (Hz)	CHABA C ₉₅	Observed C ₉₅ TTS ₂		
		Position 1	Position 2	Position 3
500	10	8	12 ^a	9
1000	10	9	4	4
2000	15	6	8	10
3000	20	10	9	5
4000	20	10	14	11
6000	20	15	15	13
Peak Pressure Level (dB)		175.0	179.6	183.7
B-Duration (msec)		9.7	10.1	9.6
Number of Ears		84	84	74

^aDenotes instance in which observed TTS₂ exceeded CHABA limit.

Table 8 summarizes the C₉₅ TTS₂ at the same three locations as shown in Table 7, but for normal-incidence exposures. At all three positions (maximum peak level 184 dB; duration 9.6 msec) the observed C₉₅ were within the limits of the CHABA DRC, except for 500 Hz at Position 3.

TABLE 8

Temporary Threshold Shift₂ at Three Normal-Incidence
Exposure Positions With Hearing Protection (Phase II)

Frequency (Hz)	CHABA C ₉₅	Observed C ₉₅ TTS ₂		
		Position 1	Position 2	Position 3
500	10	8	10	11 ^a
1000	10	4	8	4
2000	15	9	13	7
3000	20	7	17	14
4000	20	13	13	11
6000	20	19	18	14
Peak Pressure Level (dB)		175.0	179.6	183.7
B-Duration (msec)		9.7	10.1	9.6
Number of Ears		40	38	31

^aDenotes instance in which observed TTS₂ exceeded CHABA limit.

Phase III

Table 9 summarizes the results of two unprotected exposures to noise produced by M72A1 rockets at positions where the peak level and B-duration (161.9 dB; 9.3 msec) equalled the CHABA DRC limit for single impulses. Two different ear orientations, grazing from the front and grazing from the rear, were tested. The results indicate that about the same amount of TTS resulted from both orientations.

TABLE 9
Temporary Threshold Shift₂ from CHABA-Limit M72A1 Rocket Noise^a
(N = 66 Ears)

Frequency (Hz)	CHABA C ₉₅	Grazing - Rear			Grazing - Front		
		C ₅₀	C ₉₅	C ₁₀₀	C ₅₀	C ₉₅	C ₁₀₀
500	10	0	11	20	0	8	13
1000	10	0	4	15	0	7	9
2000	15	0	5	13	0	8	12
3000	20	0	11	18	0	8	11
4000	20	0	10	14	0	12	19
6000	20	0	15	21	0	12	27

^aPeak Level, 161.9 dB; B-Duration, 9.3 msec.

DISCUSSION

Phase I

One of the goals of Phase I was to validate the single-impulse correction factor of the CHABA impulse-noise DRC. The basic criterion is designed to limit TTS₂ to an acceptable level for 95 percent of individuals exposed to 100 impulses. It also includes a correction factor of 5 dB for each 10-fold change in number of impulses. Therefore, in Phase I, Ss were exposed to single impulses having markedly different B-durations, at positions where the peak pressure levels corresponded to the provisions of the DRC, i.e., the basic criterion plus 10 dB. The results summarized in Tables 3 and 4 indicate that the prediction derived from the DRC was bracketed by the results for the M72 and M20A1 exposures; therefore it may be concluded that the DRC is valid for predicting the effects of single impulses.

The second goal in Phase I was determination of the extent of the hazard to operators of the existing M72 LAW weapon. The hazard is clearly illustrated by the data in Table 6. The TTS₂ values permitted by the CHABA C₉₅ DRC were exceeded at all frequencies in both ears with the exception of 1000 Hz in the left ear. The data for the right ears, which were closest to the noise source (rear) of the rockets, indicates that up to 81 dB of TTS_{2,8} resulted from this exposure, and that the CHABA C₉₅ limits were exceeded by up to 61 dB. It has been clearly established that repeated exposures without hearing protection at such levels can eventually result in

permanent hearing loss. Also, at present there is some evidence that these amounts of TTS may render personnel severely impaired for the performance of certain critical combat-relevant tasks, such as detection of the presence of the enemy while on patrol or sentry duty. Furthermore, recovery from such large values of TTS often requires several weeks for completion and personnel are thus impaired in their ability to perform combat functions for a long period of time.

It should be noted that the $TTS_{2.8}$ data from exposure at the operator's position of the M72 LAW were not converted to the common reference TTS_2 . The reason for this omission is the relatively high incidence of $TTS > 35$ dB at this location. Kryter's correction curves (5), which were applied to all other data in this report, do not provide correction factors for $TTS > 35$ dB; thus the method was inappropriate in this instance. However, if the correction had been applied, the corrected TTS_2 would have been larger than the reported $TTS_{2.8}$. All TTS were measured more than two minutes after exposure. Thus, for example, to convert TTS_5 to TTS_2 would increase the minimal value of the TTS. Had this been done, the results would have been even more dramatically (albeit inappropriately) divergent from the CHABA C_{95} limits on TTS_2 .

The resulting $TTS_{2.8}$ for the left ears, while somewhat less than those incurred in the right ears, still clearly exceeds the limits specified by the CHABA DRC. The imbalance in TTS between the two ears causes an additional problem, since it is generally believed to render personnel unable to localize the position of acoustical targets in a tactical environment. This phenomenon is due to the unequal reduction of intensity cues reaching their ears.

One may legitimately ask why there was an imbalance in the TTS at the two ears of the firer. This question can readily be answered by reference to Figure 4, which illustrates the orientation of the operator's head with respect to the rear of the rocket. Note that the right ear is turned slightly toward the rear of the rocket, which means that the right ear is in a direct line with the noise source at the rear of the tube. By contrast, the left ear is turned in such a way as to be in the acoustical shadow cast by the head, and is therefore afforded some protection by this shadow. Also, the incidence angle of the ear is much greater for the left ear than for the right one, thereby providing the left ear with additional protection. Data similar to that reported here was previously observed in studies by Hodge and McCommons (4) in their behavioral study of the sound-shadow effect using small-arms noise.

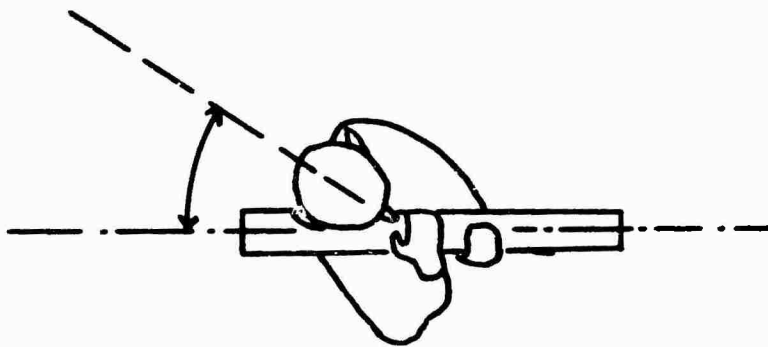


Fig. 4. OPERATOR'S EAR ORIENTATION WHEN FIRING M72 LAW
(Right ear is turned toward breech, while left ear is shadowed by head.)

This drawing is a tracing of a photograph of a soldier actually firing the M72 LAW.)

It should be noted that only 28 Ss were actually tested at the operator's position of the M72 LAW. At the outset, it was not expected that so much TTS would result from the unprotected exposure,; so it was planned to test all of the Ss under that condition. However, by the time 28 Ss had been tested, it had become sufficiently clear that we were dealing with a very hazardous condition and it was decided to terminate that particular portion of the test.

In view of the essentially random manner in which Ss were assigned to the roster for test conditions, it is worth considering whether possibly only the most susceptible Ss were tested at the operator's position of the M72. This question is unanswerable, but it is possible to estimate what the results would have looked like had the remaining 15 Ss been tested. If these 15 Ss had been distributed in the same manner as the 28 who were exposed, the resulting distribution of TTS would have been the same as that shown in Table 6. Had these untested Ss been more susceptible than the 28 who were tested, then the extent of the assessed hazard would have been even greater. Thus the critical question relates to how the results might have looked had the remaining 15 Ss' TTS's been less than the C₉₅ CHABA limits. This question can be answered by referring to Table 10 which shows the percentage of ears exceeding CHABA C₉₅ for sample sizes of 28 and 43, assuming that the additional 15 Ss' TTS s were all less than CHABA C₉₅ in magnitude. It can be seen that, even here, more than 20 percent of the ears would have demonstrated TTS in excess of the CHABA limits, a result which is unacceptable in terms of the hazards of rocket-noise exposure. Thus it may be concluded that the sampling problem imposed by premature termination of the testing at the M72 operator's position did not unduly prejudice the finding or overestimate the hazard.

Finally, mention should be made of the fact that recovery occurred following the exposure at the operator's position of the M72, even though in several cases this recovery was quite slow. (It is, of course, well known that recovery from high values of TTS can be very slow, being essentially linear in time rather than linear in log time as usually found for smaller values of TTS (7). Further, Luz and Hodge (6) have recently observed that even for smaller values of impulse-noise-induced TTS, recovery may not take place in a log-time fashion.) For TTSs of up to 70 dB, recovery was complete within 96 hours. In several cases of larger TTS, however, recovery required up to six weeks for completion.

Translating these observations into practical interpretations regarding the effect of temporary or permanent hearing loss upon a soldier's performance, is as yet tenuous, since few data exist in this area at present. It is assumed, however, that during the recovery period the Ss would have been handicapped in their ability to perform critical combat-relevant tasks, such as communication by speech or detection of the presence of enemy personnel. This latter type of performance would have been affected the most, it is believed, since the TTS s were typically largest in the 4-6 kHz region which is also the central portion of the spectrum of sounds made by personnel.

Phase II

The primary purpose of the Phase II tests was to determine the effects of small-rocket noise on the hearing of soldiers wearing well-fitted earplugs and to derive from the data recommendations about exposure limits for personnel so protected. Both grazing and normal-incidence exposures were used in order to arrive at recommendations for the operators of small rockets which might require various head orientations.

TABLE 10

Comparison of Results for 28 and 43 Right Ears, With the Absolute Number of Ears Having TTS Exceeding CHABA C₉₅ Held Constant

Frequency (Hz)	Number of Ears With TTS > CHABA C ₉₅ ^a	Number of Ears		Percentage of Ears	
		With TTS < CHABA C ₉₅ N = 28 ^a	With TTS < CHABA C ₉₅ N = 43 ^b	With TTS > CHABA C ₉₅ N = 28 ^a	With TTS > CHABA C ₉₅ N = 43 ^b
500	5	23	38	18	12
1000	9	19	34	32	21
2000	5	23	38	18	12
3000	8	20	35	29	19
4000	8	20	35	29	19
6000	9	19	34	36	21

^aObserved data from Table 6.

^bProjected data based on N = 43 (see text).

The data as presented in Tables 7 and 8 suggest that no consistently excessive TTS_2 resulted at any of the grazing or normal-incidence exposure positions. This leads to the conclusion that, at least for impulses of about 10 msec duration, the peak level at the operator's position could be at least 184 dB without presenting an excessive TTS hazard, if the operator is wearing well-fitted earplugs.

These data indicate that the V-51R earplug provides about 29 dB of protection against impulses of this type. Stated another way, the CHABA limits on peak level can be increased by 29 dB when hearing protection equivalent to the V-51R earplug is used.

It may be noted that some of the data from the protected exposures are contradictory to the above general conclusion. We have no explanation for these few contradictory observations, but believe that, taken as a whole, the grazing and normal incidence exposure data indicate that earplugs provide satisfactory protection for peak levels up to 184 dB and B-durations of 10 msec.

Phase III

The first two exposures in Phase III were conducted to verify the findings of Phase I regarding the single-impulse correction factor of the CHABA DRC and to determine whether grazing-incidence impulses arriving from the rear and from the front would produce the same effects. Comparison of the Grazing-Rear data of Table 9 with the data in Table 3 indicates that, in both instances, the CHABA DRC prediction is correct. Comparison of the two impulse-noise arrival directions of Table 9 also indicates that shock waves arriving from the rear and from the front produce equivalent effects.

A third exposure of Phase III was intended to constitute a test of the difference between the effects of normal versus grazing-incidence exposures in unprotected ears. However, the present data are contradictory to that obtained in previous studies and thus do not provide a clear answer to the question. It would seem, therefore, that further investigation of the normal versus grazing question is needed. Such research should probably utilize a different methodological approach, such as the comparison of the growth rate for TTS from normal and grazing incidence exposures performed by Hodge and McCommons in 1967 (3).

CONCLUSIONS

The foregoing results and discussion appear to support the following conclusions:

1. The single-impulse correction factor of the CHABA impulse-noise damage-risk criterion is valid; that is, the correction adequately predicts the TTS resulting from exposure to noise of small rockets, at least for impulses having B-durations of 12 and 34 msec.
2. The hazard to hearing of impulses produced by firing the M72 LAW, having a peak pressure level of 179.7 dB and a B-duration of 12 msec, is greatly in excess of the limits of the damage-risk criterion. Personnel should not be exposed to such conditions without hearing protection.
3. When the firer's head is oriented as it is in firing the M72 LAW and similar weapons, the hearing loss in the ear nearer the rear of the rocket will be significantly greater than in the ear that is shadowed by the head.

4. V-51R earplugs, properly sized, fitted and inserted, provide about 29 dB of attenuation of rocket-impulse noises.

5. Use of well-fitted hearing protection (equivalent to V-51R earplugs) will permit the peak level of 10 msec impulses to be increased to at least 184 dB without excessive risk of operator hearing impairment.

6. Grazing-incidence impulse noises produce approximately equivalent effects when they arrive at the ear from the rear and from the front.

RECOMMENDATIONS

1. The use of hearing protective devices should be mandatory whenever the impulse noise in the operator's position of a weapon exceeds that allowed by the CHABA damage-risk criterion.

2. Research should be continued on means for reducing the weapon-noise hazard to operators.

RECOMMENDATIONS FOR FOLLOW-ON RESEARCH

A three-phase program should be conducted to determine why hearing protectors are not being worn and what can be done to insure that they are used, particularly when firing weapons such as LAW.

Phase I would consist of a survey of the use of hearing protectors within the Army. It would determine the extent of usage in basic training, advanced individual training, etc. Usage in combat and compatibility of protectors with operational requirements would be examined. Compatibility with clothing, helmets, gas masks, etc., would be determined. Objections to utilization of hearing protectors should be surveyed, as should circumstances in which they could be (but are not) worn in combat situations. This phase of the program would be coordinated with the Surgeon General's Office and with the Natick Laboratories.

In Phase II a catalog of available hearing protectors would be developed. These would include ear plugs, ear muffs, semi-inserts, non-linear types, etc. Specific user-situations would be identified under which the various types of protectors would be most appropriate (e.g., in terms of degree of protection afforded and compatibility with equipment and/or operational requirements). The characteristics which a protector must possess in order to be acceptable to various user groups would be determined.

Phase III would consist of determining the protection afforded by various types or classes of protectors. This could be done by measuring pure-tone and impulse-noise attenuation by psychophysical and/or physical methods. Exposing subjects to noise, using methodology akin to that reported above, could also be used to determine the hazards of exposure to various weapons' noise with and without hearing protection. The temporary hearing loss data would be utilized to estimate the impairment of soldiers' performance in tactical situations, and the risk of permanent hearing loss which would result from repeated unprotected exposure.

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2. Garinther, G. R., & Moreland, J. B. Transducer techniques for measuring the effect of small-arms' noise on hearing. Technical Memorandum 11-65, Human Engineering Laboratories, Aberdeen Proving Ground, Md., 1965.
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APPENDIX A

NOISE MEASUREMENTS

For measuring the impulse noise of weapons, the proven procedures of HEL Technical Memorandum 11-65 (2) require:

- a. Use of a transducer having a rise time capability of 10 μ sec or less at the pressure being measured.
- b. Use of a measurement system having a uniform frequency response characteristic at least between 100 Hz and 70 kHz.
- c. Orientation of the transducer at grazing (90°) incidence in relation to the noise source.

The transducer selected was a Susquehanna Instrument model ST-2 lead metaniobate pressure transducer, connected directly to a Piezotronics model 401A11 emitter follower feeding 35 m of RG-58 coaxial cable, followed by a Piezotronics model 482A power supply. A Tektronix model 556 oscilloscope with a C-12 camera was used to capture the pressure-time history. Prior to and following its use, the system was calibrated in the HEL shock-tube facility. As added verification of this system's accuracy, its output was compared to that of a Bruel and Kjaer (B&K) model 4136 $\frac{1}{4}$ -in. capacitor microphone at a pressure where both transducers respond accurately. Pressure-time histories were obtained simultaneously with both transducers at 10 m to the side of the M72 and M20A1 rockets. The Susquehanna ST-2 and B&K 4136 transducers indicated peak pressure levels of 156.2 and 156.0 dB, respectively, for the M20A1, and 160.3 and 160.8 dB, respectively, for the M72. Wave shapes for both weapons, as indicated by the two transducers, were essentially the same, as shown in Figures 1A and 2A. The B&K microphone was not used in this program because at pressure levels of 180 dB its rise-time capability is greater than 10 μ sec.

Two matched ST-2 transducers (SN 2055 and 2104) were selected for use in the program. The sensitivity of both transducers was 108 mv per PSI prior to, and following, the test.

During Phase I of this program three measurements were made during the noon break of each daily exposure. Transducers were located at a point where the downrange ear would have been, with the S absent. Peak levels and durations for each location are shown in Table 1A. In addition to these measurements a second transducer, used as a reference during each exposure, was located 10 m from the weapon on an azimuth of 90° from the sight. Its purpose was to detect any abnormal round-to-round variation in noise parameters produced by the weapon during exposures. There were none.

TABLE 1A

Peak Pressure Level and Duration Measured at the
Exposure Positions of Phase I

Distance (m)	Peak Level (dB)		Duration (msec)		n
	Mean	S.D.	Mean	S.D.	
M72					
8	160.8	1.3	12.3	0.3	6
2.5	169.5	1.9	14.1	0.6	6
Firer's rt. ear	179.7	2.3	12.0	0.6	9
M20A1					
4	159.3	1.5	34.1	0.7	9

TABLE 2A

Phase II Noise Measurements at Selected Transducer Locations

Distance from Breech (m)	Over Chin Rest		33 cm Right of Chin Rest (Downrange) ^a			
	Peak Level ^b	Duration ^c	With Head		Without Head	
			Peak Level	Duration	Peak Level	Duration
4.0	174.4	9.6	173.3	10.3	173.3	9.9
2.3	180.1	10.9	178.4	10.2	178.4	11.2
1.5	184.1	10.4	180.3	11.3	181.0	10.7

^aSubject facing away from breech at 45°.

^bdB re 20 $\mu\text{N}/\text{m}^2$.

^cEnvelope duration (msec).

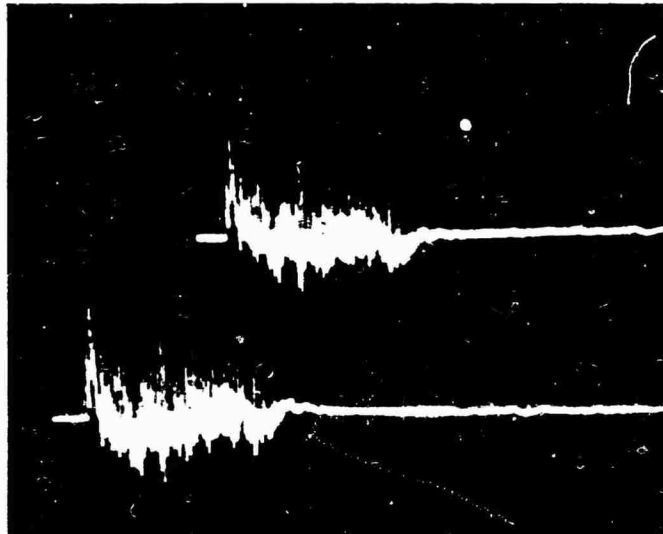


Fig. 1A. PRESSURE TIME HISTORY PRODUCED BY THE M20A1 WHEN MEASURED WITH THE MODEL ST-2 (UPPER TRACE) AND TYPE 4136 (LOWER TRACE) TRANSDUCERS

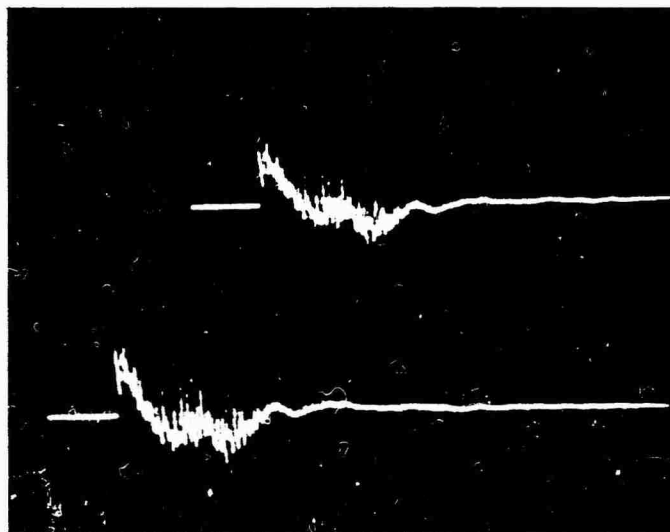


Fig. 2A. PRESSURE TIME HISTORY PRODUCED BY THE M72 WHEN MEASURED WITH THE MODEL ST-2 (UPPER TRACE) AND TYPE 4136 (LOWER TRACE) TRANSDUCERS

NOT REPRODUCIBLE

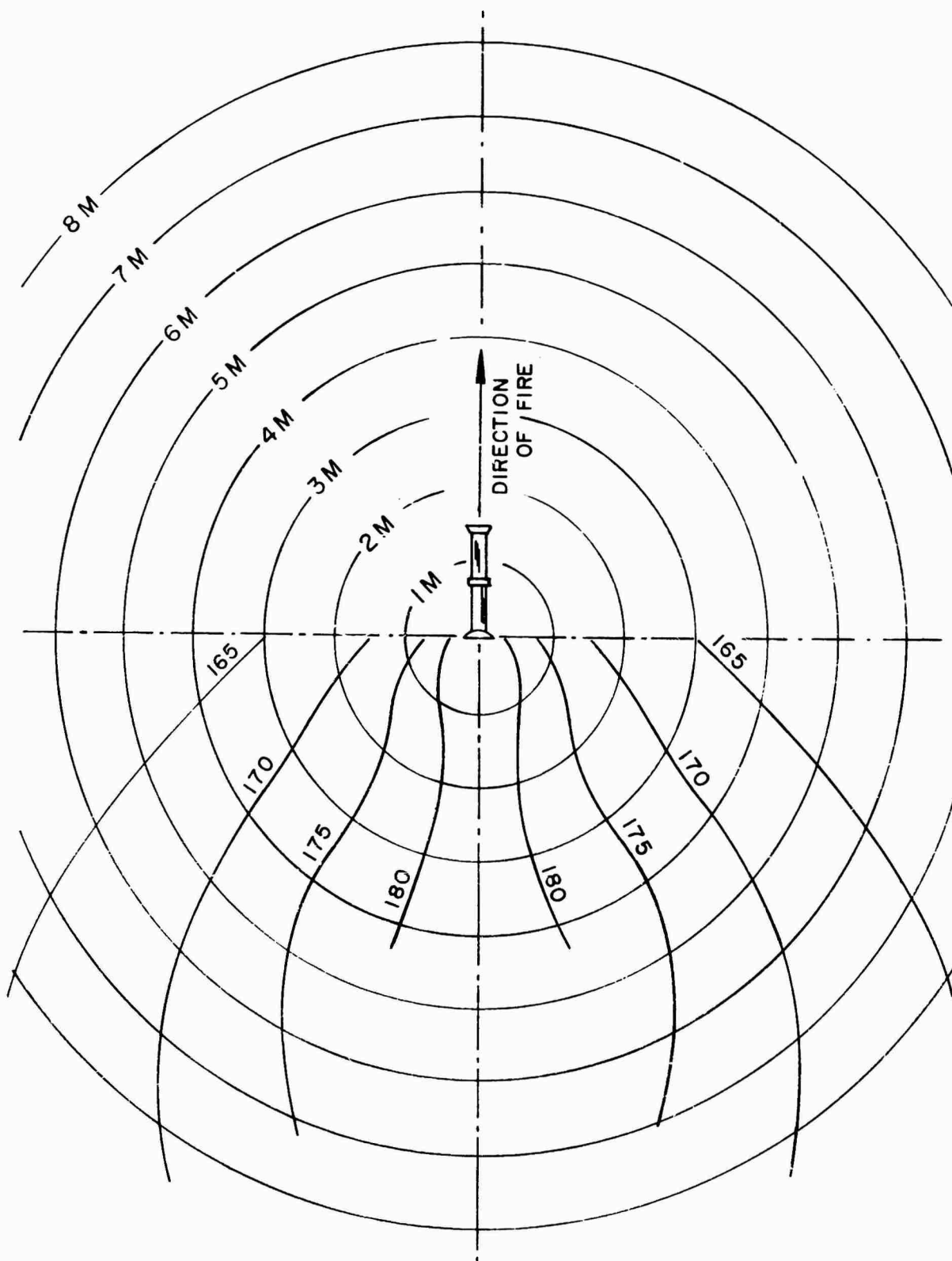


Fig. 3A. EQUAL-PRESSURE CONTOURS (IN dB) AROUND THE M20A1 ROCKET LAUNCHER

For Phase II, which was conducted along azimuths of 45° from the breech of the weapon, it was decided to measure the noise parameters near the S for each exposure. A bracket was therefore constructed which positioned the transducer at ear height 33 cm to the side of the center of the chin rest. Prior to the exposure, measurements were made at each exposure location with and without the S in place to determine the effect of the S's head on the pressure-time history indicated by the transducer. In addition, measurements were obtained at a point directly over the center of the chin rest. These data are shown in Table 2A. As can be seen from Table 2A there was a larger difference at 1.5 m between the peak level measured over the chin rest and that measured at the 33 cm position than at greater distances. This is understandable since the pressure contours around the breech of a rocket do not diverge spherically. Pressure becomes much greater as one moves toward the rear of the weapon. Figure 3A shows the equal-pressure contours for the M20A1 rocket. It can be seen that when moving along a constant radius toward the rear of the weapon the pressure increases significantly.

During the grazing-incidence exposures of Phase II, the transducers were located directly to the side of the downrange ear at ear height (Fig. 4B) of each S.

For the normal-incidence exposures (Phase II) the transducers were located directly in front of the Ss at ear height (Fig. 6B).

Subjects were exposed and measurements were made at symmetrical locations on both sides of the weapon. Comparison of the measurements made on the left and right sides of the weapon indicated a difference of less than 1 dB for all conditions tested.

The peak level and duration for the exposures at 1.5, 2.3 and 4.0 m were obtained by averaging those measurements made downrange (grazing incidence) and uprange (normal incidence). The averages of these two measurements represents the peak level and duration at the center of the head (Table 2, main text).

During Phase III of the program, the peak level and duration at 21 m were obtained in the same manner as for Phase II.

APPENDIX B

PHOTOGRAPHS SHOWING SUBJECT EXPOSURE POSITIONS

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Fig. 1B. SUBJECT EXPOSURE POSITIONS ADJACENT TO M72 ROCKET IN PHASE I
(Note chin rest used to insure constant ear position. Circle shows microphone used to monitor rocket noise on each shot.)

NOT REPRODUCIBLE



Fig. 2B. SUBJECT EXPOSURE POSITIONS ADJACENT TO M20A1 ROCKET IN PHASE I

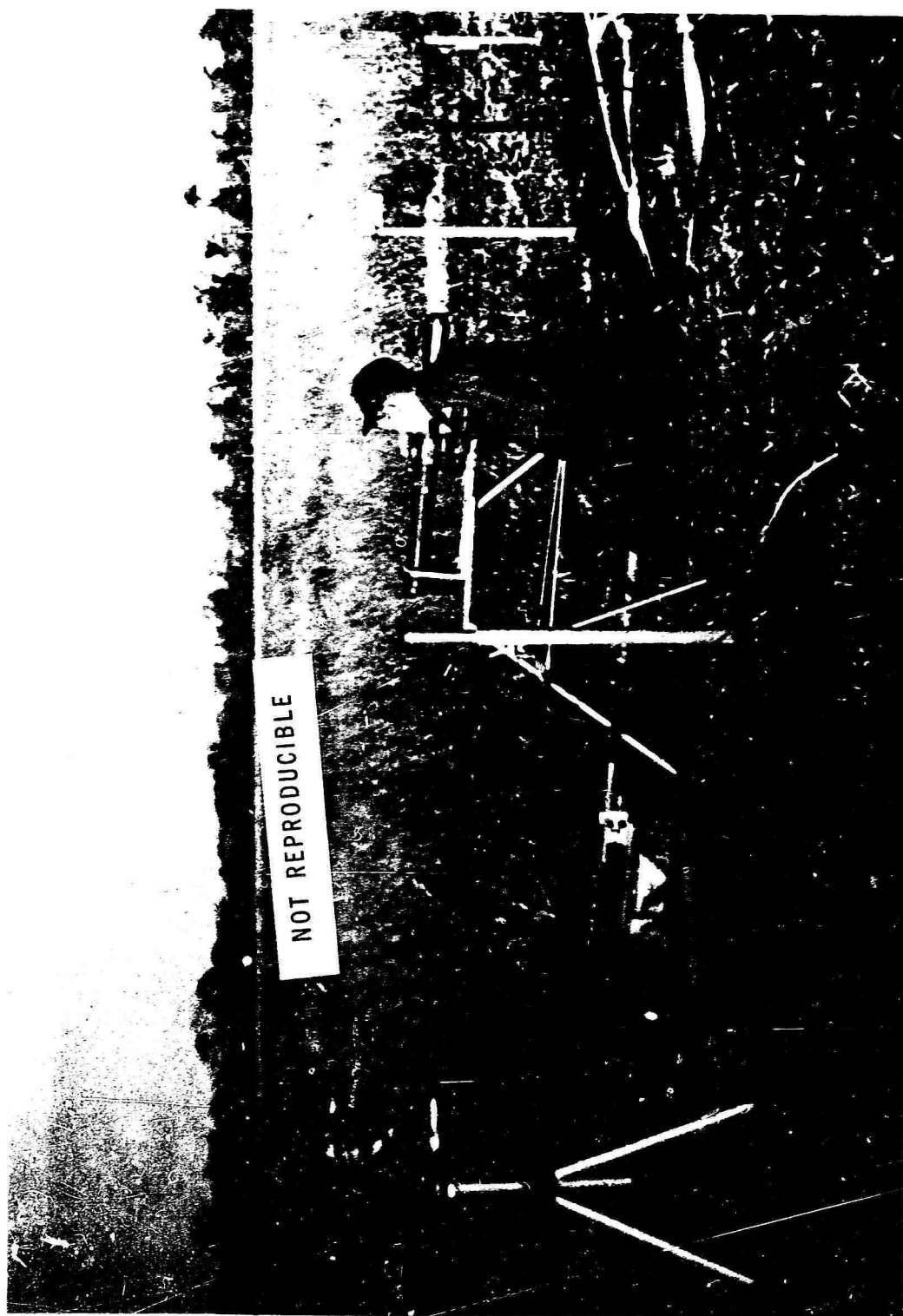


Fig. 3B. SUBJECT EXPOSURE POSITION 3 (OPERATOR'S POSITION) FOR
M72 ROCKET IN PHASE I
(Only one subject was exposed per shot for this condition.)

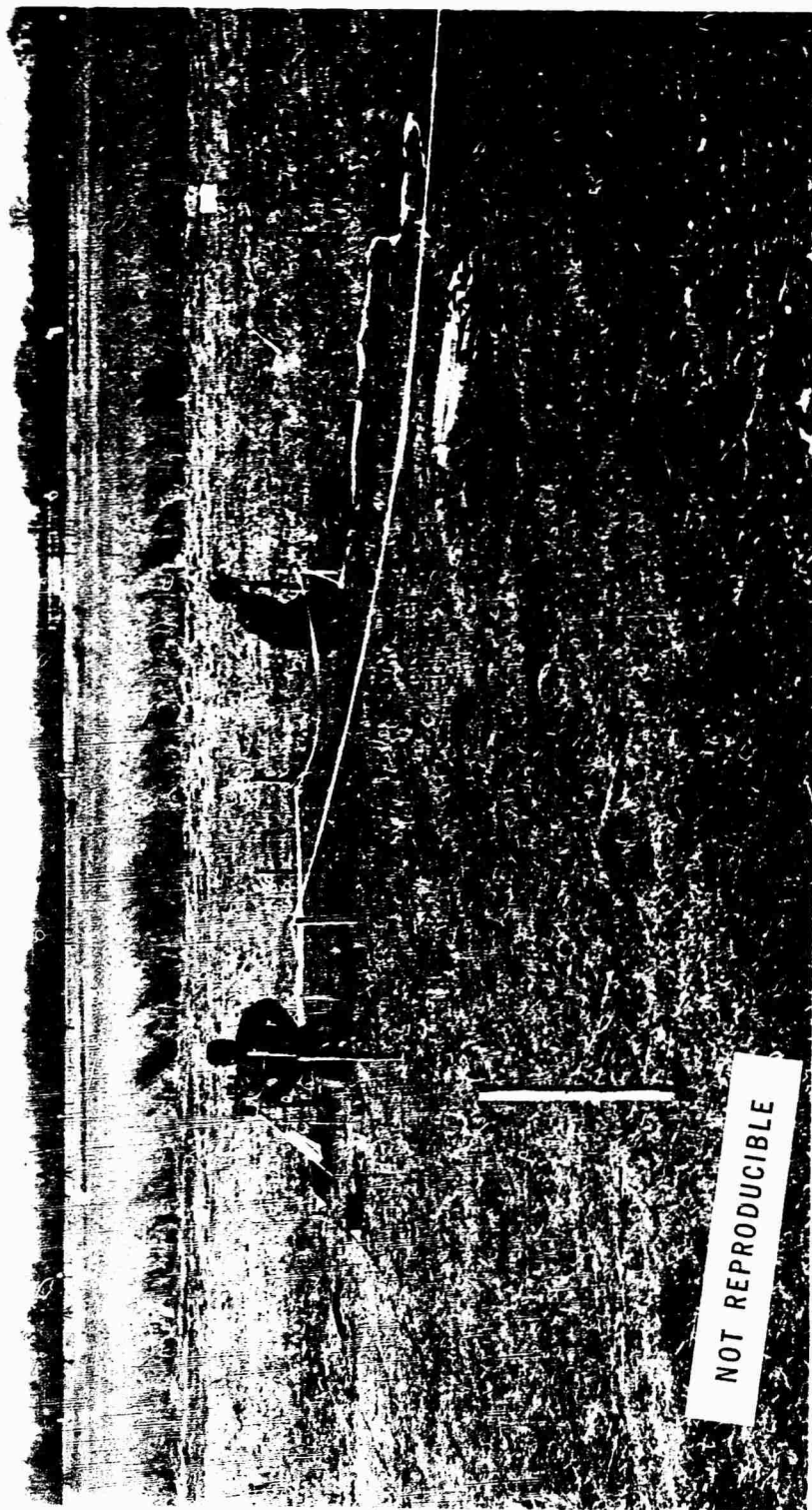


Fig. 4B. PHASE II SUBJECT LOCATIONS (GRAZING INCIDENCE)
(Note: For this shot the two subjects were exposed at different locations.)

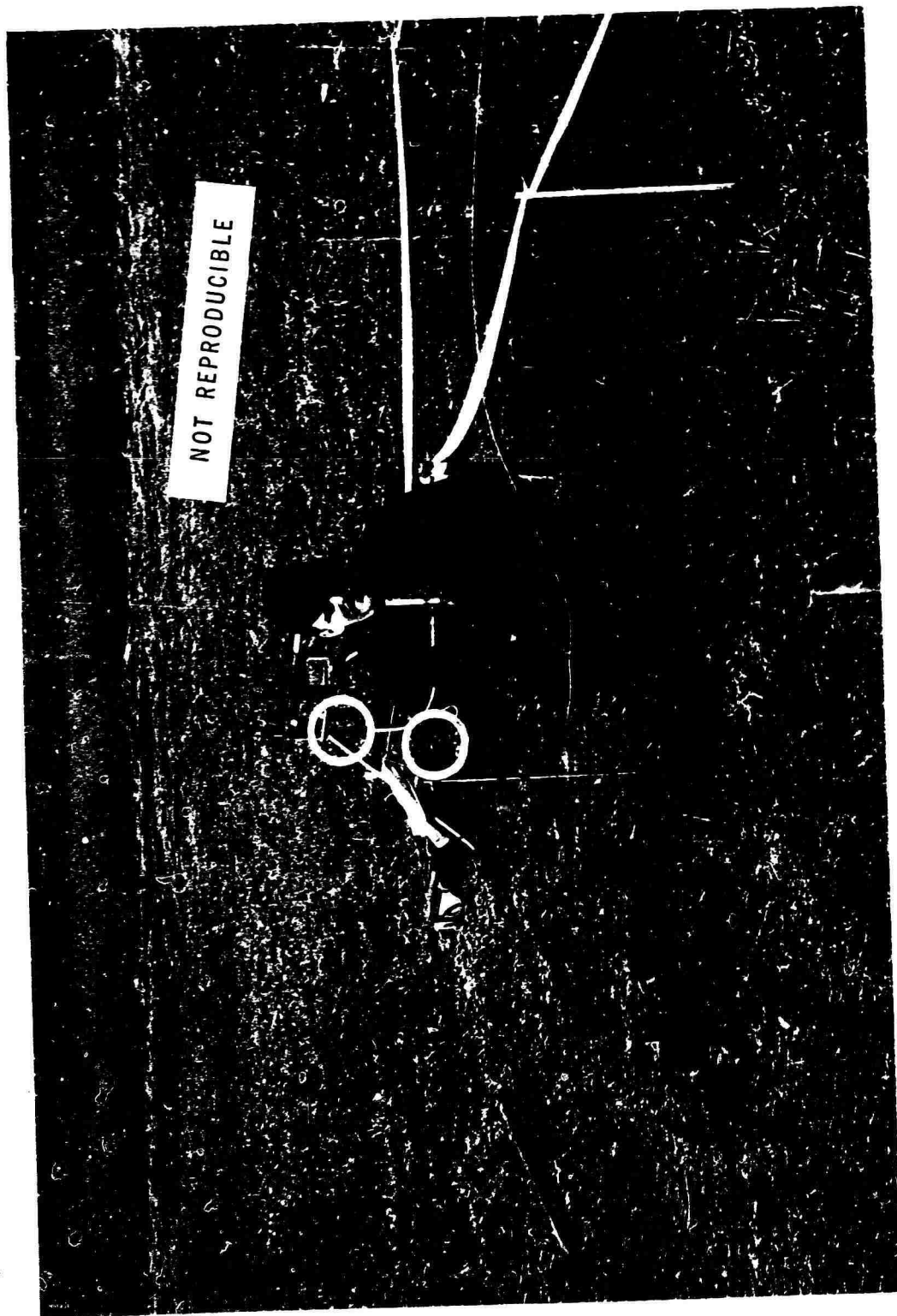


Fig. 5B. CLOSE-UP OF PHASE II SUBJECT POSITION (GRAZING INCIDENCE)
(Upper circle shows microphone used to monitor rocket noise on each shot.
Lower circle shows trigger microphone. Identical equipment was used
at the other subject's position.)

NOT REPRODUCIBLE

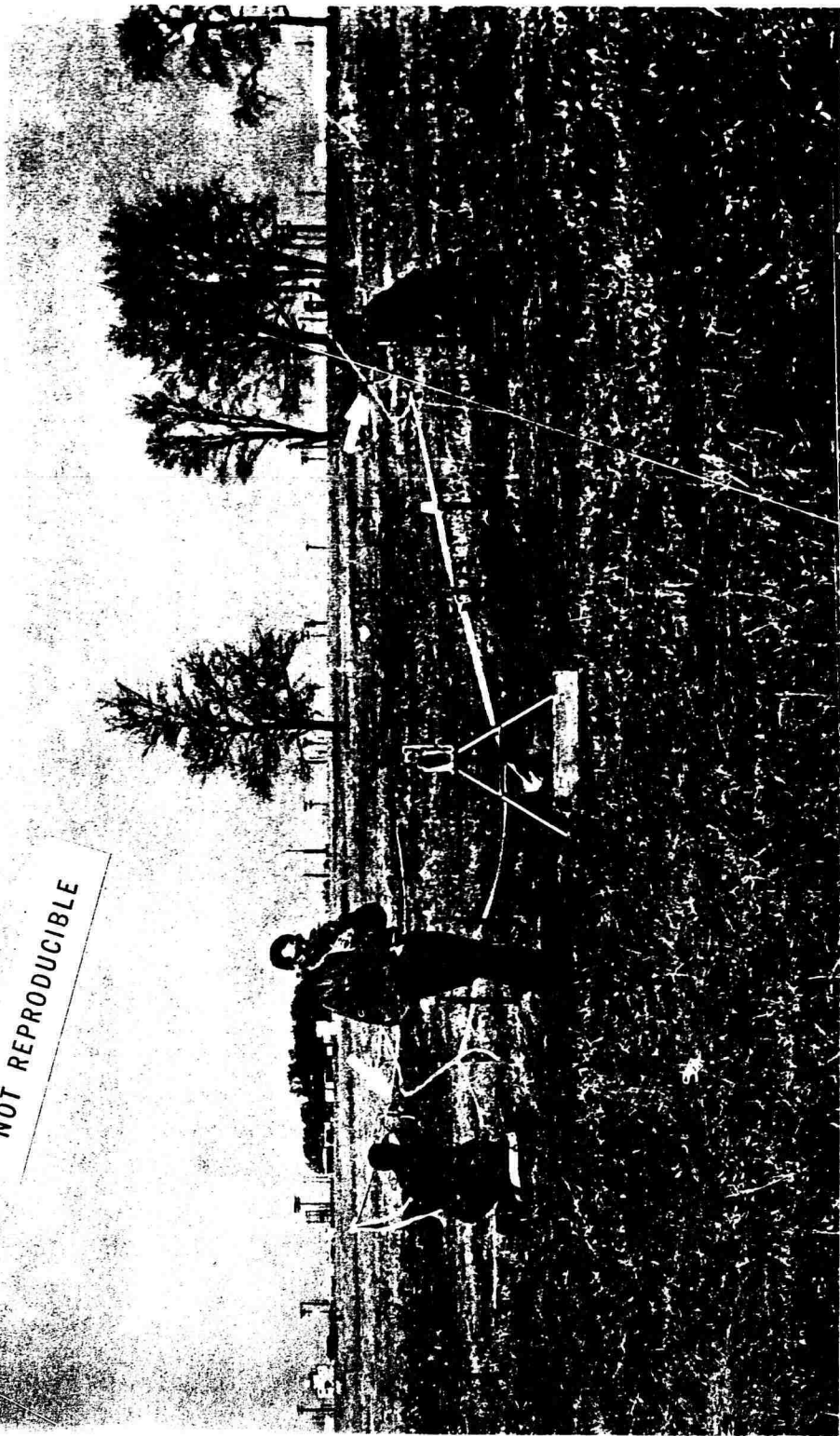


Fig. 6B. PHASE II SUBJECT POSITIONS FOR NORMAL-INCIDENCE EXPOSURES
(Arrow shows measuring microphone location. Test director has just checked
ear plug fit and is preparing to arm rocket for the shot.)